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NASA TECHNICAL TRANSLATION NASA TT, F-14,291

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(NASA-TT-F-14291) MOVEMENT OF SOIL MOISTURE UNDER TEMPERATURE GRADIENTS Y. Suzuki (Scientific Translation Service) Jun. 1972 20 p CSCL 08M

N72-26293

Unclas

G3/13 31679

Translation of "Ondo keidoka ni okeru dojo suibun no ido," Journal of Agricultural Meteorology of Japan (Nogyo kisho), Vol. 18, No. 3, December 1962, pp 98-104

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 JUNE 1972

MOVEMENT OF SOIL MOISTURE UNDER TEMPERATURE GRADIENTS *

Yoshinori Suzuki **

ABSTRACT. The effect of a temperature gradient on the movement and distribution of soil moisture has been examined in closed column of soil for various initial water contents (1% ∿ 7%).

The results are as follows:

(1) In all except the dryest and wettest columns of soil there was a transfer of moisture towards the colder end from the warmer, that is, water evaporating from the hotter soil moves as vapor into colder soil, where it condenses and returns as liquid when a favorable gradient of moisture has been established.

(2) For the transfer of soil moisture, liquid flow works as a control factor and reduces the amount of net transfer due to temperature gradient.

(3) The amount of transfer of soil moisture varies with the initial water content, and for sand (particle size 0.175 ∿ 0.5 mm) the maximum transfer of moisture from the hot to the cold end occurred at between 3.5% and 4.0% of the initial water content which is approximately one third of the moisture equivalent.

(4) The observed net transfer of moisture coincides with the vapor flows calculated by the diffusion equation of Penman, Krischer & Rohnalter, et al. quite well at the maximum transfer of moisture, but not in other ranges of initial water content.

1. INTRODUCTION

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There has been much interest recently in the physical properties concerning the movement of moisture and heat in porous materials in the presence

*Delivered at the national convention on April 6, 1962.

**Kyushu Agricultural Experiment Station.

***Numbers in the margin indicate pagination in the original foreign text.

of temperature gradients. This is an extremely important question, not only from the standpoint of research in microclimate and microhydrography, but also from the engineering standpoint. Considerable advances have been made in physical theory concerning numerous microhydrographical phenomena where there is a tendency towards easily becoming isothermal, but it appears that no clear-cut mechanism has yet been established for the movement of moisture under temperature gradients. The reason for this is that, at the present stage of research in this field, quantitative analysis is impossible in most cases. In other words, this is because the boundary conditions are too complex, and further because measurements are difficult to make. Bouyoucos is said to have been the first to take notice of moisture movement under temperature gradients. Since then, this phenomenon has been studied by a large number of researchers, such as Smith, McLean and Gwatkin, and others. That is, Bouyoucos (1938) [1] found that when a soil column is divided in two by a void and when there is a temperature gradient cutting across it, the amount of moisture which moves is less than in a continuous column. His conclusion was that, "flow must occur on a larger scale in the liquid phase." Smith (1943) [2] proposes a liquid flow mechanism in which the vapor inside the capillary pores condenses from the warm to the cold end; the combined substance lacks equilibrium. The water moves on account of an ordinary capillary effect, going up inside the pores in the low-temperature part immediately above. A mechanism based on vapor diffusion theory was proposed by Penman [3], Krischer & Rohnalter, Stefan, de Vries and Philip [4]. Gurr et al. also made the fact clear by experiments that the vapor phase moves from warm to cold, while the liquid phase moves in the opposite direction. Since the writer also performed simple experiments concerning this, the results are reported.

2. OUTLINE OF RESEARCH ON MOISTURE MOVEMENT IN THE SOIL

The patterns of moisture movement in the soil can be classified in the following manner. First, there is moisture movement as a liquid phase; there is also movement as a vapor phase. Besides, there are cases when both of these occur at the same time. When there is water saturation, the movement is liquid phase movement. This can be divided up chiefly into movement in the vertical direction on account of gravity, and movement in the horizontal direction on account of pressure head differences. On the other hand, in the unsaturated state, movement occurs in both the liquid phase and the vapor phase. Movement is caused by capillary force and by gravity, and it is assumed that movement on account of vapor diffusion alone occurs in the unsaturated state when there is an extremely low water content. Since the author carried out experiments concerning unsaturated soil, this paper discusses sections with a low water content.

In unsaturated soil, whenever the liquid continuity is broken, the moisture in each area assumes the form of lumps. If these are called "liquid islands," the curvatures of both islands will be identical, as long as a thermodynamical state of equilibrium is being maintained. However, when there is a temperature field, it is conceivable that the vapor pressure gradient caused by it may cause vapor flow in the arrow direction in Figure 1 (A). As a result of the condensation at (a) and the evaporation at (b), there is a tendency for the curvature on the (a) side to decrease and for the curvature on the (b) side to increase. This tendency continues until the difference between the (a) and (b) curvatures becomes so great that the capillary flow passing through the resulting islands brings the degree of condensation at (a) to a point where it is identical with the degree of evaporation at (b).

Next let us consider this from the viewpoint of the soil as a whole. Since soil is a porous substance consisting of three components — soil grains, liquid phase, water, and air — when there are temperature gradients in it, the vapor pressure of the air in contact with the water film on the high temperature side becomes higher than the vapor pressure on the low temperature side. This results in vapor diffusion towards the lower vapor pressure. Moving towards the cold side, the vapor is cooled, is condensed, emitting heat of condensation, and becomes liquid phase water. The liquid phase water moves towards the warm side, where there is a low water content, as a result of

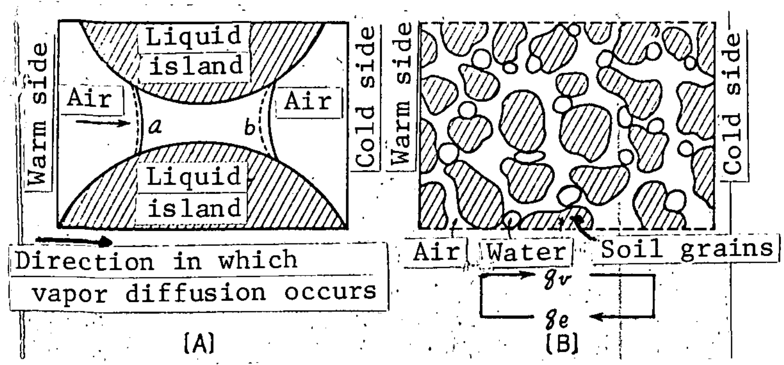

Figure 1. Model diagrams of moisture movement.

capillary action. Here it is heated again, evaporates to become steam, and repeats diffusion. Consequently, the moisture in the soil goes through the following process: diffusion (hot side) → condensation (cold side) → capillary action (caused by the moisture gradient) → evaporation (hot side) → diffusion. In this case, the moisture on the cold side steadily increases until the capillary action becomes effective. A model of this is shown in Figure 1 (B) [5].

(i) As for theoretical equations concerning vapor diffusion in porous materials, Penman, Krischer & Rohnalter, Van Varvel, and Rolin gave the following equation, saying that the "vapor flow rate is in direct proportion to the vapor density gradient" [4]

$$q_v = -D_{atm} \cdot \nu \cdot \alpha \cdot a \cdot \nabla \rho_v \qquad (1)$$ /99

Here, q_v : vapor flow

D_{atm} : molecular diffusion coefficient of steam in air

ν : $P/(P - p)$

α : resistance coefficient to diffusion

a : air volume ratio

ρ_v : density of steam

Krischer and Rohnalter state that within the range of 20 - 70° C, the following applied to the value of D_{atm}:

$$D_{atm}=4.42\times 10^{-4}\cdot T^{2.3}P^{-1}$$

The following applies generally in thermodynamics:

$$\rho_v=\rho_0\cdot h=\rho_0\cdot \exp\ (\Psi g/RT) \tag{2}$$

ρ_0: saturation steam pressure

h : relative humidity

Ψ : water pressure

g : acceleration of gravity

R : gas constant of steam

T : temperature °K

ρ_0 is a constant of T only, and h is a constant of the moisture θ only. Therefore, when Equation (2) is differentiated, the following is obtained:

$$\nabla\rho_v=h\cdot\frac{d\rho_0}{dT}\cdot\nabla T+\rho_0\cdot\frac{dh}{d\theta}\cdot\nabla\theta \tag{3}$$

When $dh/d\theta$ is sought from the right side of Equation (2) and is inserted, the following is obtained:

$$\nabla\rho_v=h\cdot\frac{d\rho_0}{dT}\cdot\nabla T+\frac{g\rho}{RT}\cdot\frac{\partial\Psi}{\partial\theta}\cdot\nabla\theta \tag{4}$$

From Equations (1) and (4), we have

$$\begin{aligned}\frac{q_v}{\rho_l}=&-D_{atm}\cdot\nu\cdot\alpha\cdot a\cdot h\cdot\frac{d\rho_0}{dT}\cdot\frac{\nabla T}{\rho_l}\\&-D_{atm}\cdot\nu\cdot\alpha\cdot a\cdot\frac{g\rho_v}{RT}\cdot\frac{\partial\Psi}{\partial\theta}\cdot\frac{\nabla\theta}{\rho_l}\end{aligned} \tag{5}$$

Therefore,

$$\frac{q_v}{\rho_l}=-D_{Tv}\cdot\nabla T-D_{\theta v}\cdot\nabla\theta \tag{6}$$

Here,

$$D_{Tv}=D_{atm}\cdot\nu\cdot\alpha\cdot a\cdot h\cdot\frac{\beta}{\rho_l} \tag{7}$$

$$D_{3v} = D_{atm} \cdot \nu \cdot \alpha \cdot a \frac{g\rho_v}{RT} \cdot \frac{\partial \Psi}{\partial \theta} \cdot \frac{1}{\rho_l}$$

$$\beta = \frac{d\rho_0}{dT} \tag{8}$$

In this manner, the flow rate is divided up into two components depending upon the temperature gradient (∇T) and the moisture gradient ($\nabla \theta$). Therefore, if there are temperature and moisture gradients in the soil, the flow of moisture can be calculated by means of Equation (6).

(ii) Movement of the Liquid Phase

Darcy's law concerning liquid phase movement is as follows:

$$\frac{q_l}{\rho_l} = -K \cdot \nabla \Phi \tag{9}$$

K : coefficient of infiltration

Φ : hydraulic gradient

If Φ contains pressure and gravity components,

$$\Phi = \Psi + z \tag{10}$$

Within the range of θ where movement of the liquid phase occurs, Φ is determined by the capillary effect. Therefore,

$$\frac{\partial \Psi}{\partial T} = \frac{\Psi}{\sigma} \cdot \frac{d\sigma}{dT} = \nu \cdot \Psi \tag{11}$$

σ : surface tension.

In view of Equations (9), (10), and (11), we have

$$\frac{q_l}{\rho_l} = -K \nabla \Phi = -K(\nu \Psi \cdot \nabla T) - K\left(\frac{d\Psi}{d\theta}\right) \cdot \nabla \theta - K_i \tag{12}$$

i : unit vector in the positive direction of z.

Equation (12) obviously signifies the following:

$$\frac{q_l}{\rho_l} = -D_{Tl} \cdot \nabla T - D_{\theta l} \cdot \nabla \theta - K_l \tag{13}$$

Consequently, the liquid phase flow rate can be divided up into three: that caused by the temperature gradient, that caused by the moisture gradient, and that caused by gravity. The diffusion of the warm liquid is:

$$D_{Tl} = K \cdot \nu \cdot \Psi \tag{14}$$

In all of the theoretical equations above, it is assumed that there is ∇T, and the temperature gradients of the unit lengths of the soil grains, water, and air were taken into consideration. On the other hand, de Vries and Philip, taking into consideration both the liquid phase and the gas phase, considered the temperature gradient inside the pores $(\nabla T)_a$ as the source of energy bringing about the vapor flow. If the porosity ratio is $(a + \theta)$, the steam flow rate obtained on the basis of this concept will be:

$$\begin{aligned} &-(a+\theta) \cdot D_{atm} \cdot h \cdot \nu \cdot \beta \cdot (\nabla T)_a \\ &= -D_{Tv} \cdot \nabla T \end{aligned} \tag{15}$$ /100

Consequently, the ratio between the vapor flow rate given before and this, η, will be:

$$\eta = \frac{(a+\theta)}{\alpha \cdot a} \cdot \frac{(\nabla T)_a}{\nabla T} \tag{16}$$

Here, $\frac{(\nabla T)_a}{\nabla T} (=\zeta)$. In other words, according to de Vries [4], the following Table 1 was obtained theoretically for the ratio of the mean temperature gradient inside the pores with reference to the total temperature gradient. On the other hand, Woodside and Kuzmak (1958) [6] also obtained $\zeta = 2.09$ by de Vries' method. However, a value of $\zeta = 6$ has been obtained experimentally.

Consequently, with respect to a porosity ratio of 50% and a water content ratio of 10%, we obtain:

$$\frac{q_v}{\rho_l} = -1.9(a+\theta) \cdot D_{atm} \cdot h \cdot \nu \cdot \beta \cdot \nabla T \tag{17}$$

TABLE 1. VALUES OF ς

θ	Values of $(a + \theta)$		
	0.7	0.5	0.3
0.0	1.4 (144)	1.9 (2.0)	3.0 (3.2)
0.1	1.3 (1.4)	1.7 (1.9)	2.0 (2.7)
0.3	1.5 (1.6)	1.7 (2.0)	2.1 (2.9)
0.5	1.5 (1.6)	1.8 (2.2)	—

Yolo light clay: values for quartz are enclosed in parentheses.

In the following we give the values calculated by the writer for the physical variables.

TABLE 2. VALUES OF D_{atm} AND ν

	20°C	30°C	40°C
D_{atm}	0.247	0.286	0.298
ν	1.023	1.042	1.073

h: 1.0 (at pF 4.5 or less, it may always be assumed to be 1.0)

α: 1/3 (according to Penman and de Vries)

3. TEST EQUIPMENT AND METHOD

[Test Samples] Sandy soil from the Kyushu University campus was sifted to obtain a soil grain composition of 0.175 - 0.5 mm. The clay content was remarkably small. The same sand was used as the samples throughout all of the experiments. 10 kg of wind-dried soil was taken and watered with a sprayer; the following results were obtained as the initial moisture:

(a) 1.9% (b) 3.6% (c) 3.9% (d) 5.6% (e) 6.9%

The samples were left to stand for at least 48 hours after watering to wait for the moisture distribution to settle down.

[Test Equipment] The equipment is depicted in Figure 2. A small, tin soil tank (25 cm x 20 cm x 25 cm) was buried in the central part of a large wooden water tank (100 cm x 40 cm x 30 cm). A PVC cloth was laid over the sample in the soil tank, and a wooden cover was put on. A PVC cloth was laid over to cover this. This was done in order to prevent movement of the external air as far as possible.

[Mechanism of the Temperature Gradient] Tap water (19 - 23° C) was put into part A, and a heater and a thermostat to control it were put into part B to warm up the water (45 - 48° C). The warm water was stirred by a motor with a stirrer in order to give it a constant temperature.

[Temperature Measurements and Moisture Measurements] As a rule, the temperature gradient was given for 72 hours. The temperature changes were tracked by means of a self-recording thermometer. In this case, five thermocouples were inserted into the soil to a depth of 10 cm from the top, each at distances of 2.5 cm from the cold water side and warm water side. The intervals between them were each 5 cm. On the other hand, gypsum blocks were arranged in accordance with the thermocouples for measuring the moisture.

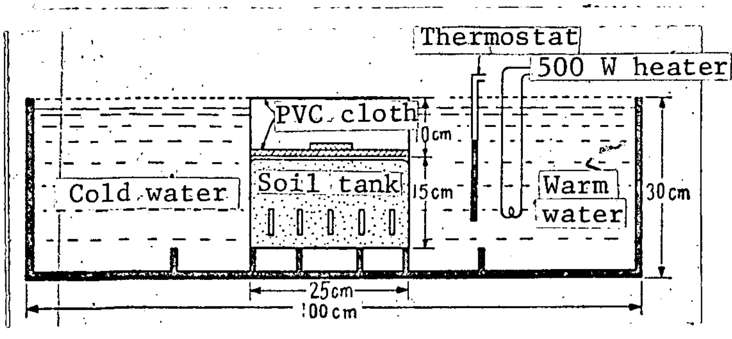

Figure 2. Test equipment

Since it was anticipated in this case that the moisture flow and the heat flow would move along the long axis, the elements were arranged at right angles to these directions in order to minimize the effects of the moisture flow and heat flow on the element rods.

As for the moisture, the resistance values of the gypsum blocks were measured from time to time, but this was not very successful on account of the soil grains and the nature of the soil. Therefore, a sampler was used the last time only to take samples of soil at a distance of 0.5 cm away from the wall surface. Next, about 10 g of soil was taken at a total of seven points at 4 cm intervals. The moisture ratio in the soil was measured by the oven drying method. The moisture content shown is the mean value of the upper and lower layers. Since the volume of the sample is known, the virtual specific gravity was sought by calculations.

4. TEST RESULTS

(i) Moisture Distribution: The final moisture distribution after a temperature gradient had been given for 72 hours is shown in Figure 3 (a, b, c, d, e).

(ii) Temperature Distribution: The time required to establish a temperature gradient in the soil tank varied, depending upon the amount of initial moisture, but was within the range of three to four hours. Typical examples of the time variations of the temperature in the soil and of the final temperature distribution after the prescribed time are shown here (Figure 4). /101

(iii) Porosity Ratio: Typical examples of the distribution of the moisture volumetric ratio and of the air volumetric ratio are shown in Figure 5. These cases also pertain to the final time.

The results of the preceding can be summarized as shown in Table 3.

5. CONSIDERATION OF THE TEST RESULTS /102

(i) Distribution of the Moisture Content According to the Temperature Gradient

As seen in Figure 3, it is clear that soil moisture in general moves away from high temperatures towards low temperatures. The conditions of

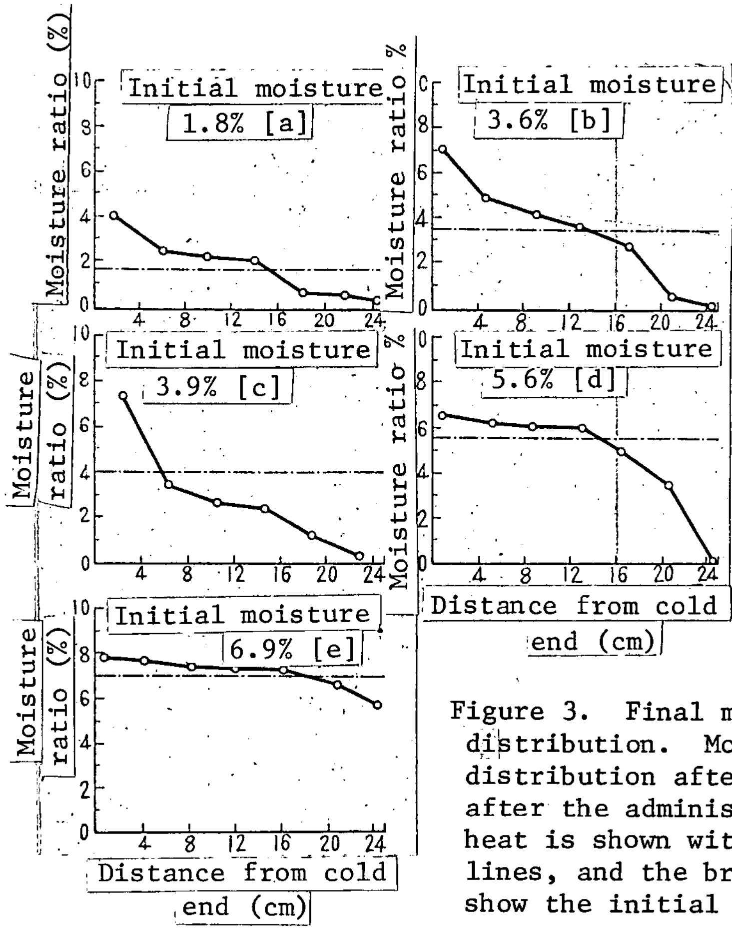

Figure 3. Final moisture distribution. Moisture distribution after 72 hours after the administration of heat is shown with solid lines, and the broken lines show the initial moisture.

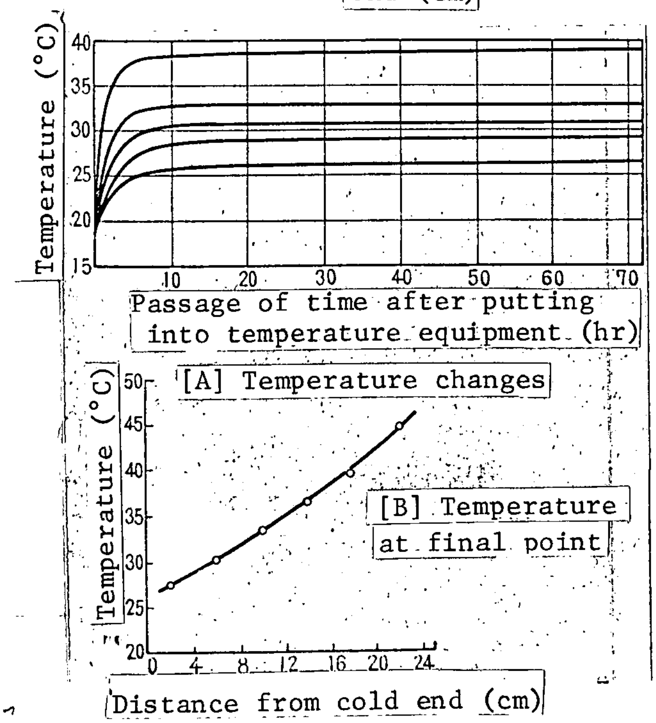

Figure 4. Temperature changes during experiments and temperature distribution at the final point (after 72 hours).

TABLE 3. RESULTING VALUES

Initial moisture	Distance from cold end (cm)	Moisture ratio (%)	Porosity ratio (%)	Moisture volumetric ratio (%)	Air volumetric ratio (%)	Virtual specific gravity
1.8%	0.5	4.0	54.4	4.7	49.7	1.19
	4.5	2.5	51.5	3.2	48.3	1.26
	8.5	2.3	49.9	3.0	46.9	1.30
	12.5	2.1	49.7	2.7	47.0	1.31
	16.5	0.6	48.5	0.5	48.0	1.34
	20.5	0.5	49.3	0.1	49.2	1.32
	24.5	0.2	50.0	0.0	49.9	1.30
3.6%	0.5	7.0	55.0	8.2	46.7	1.18
	4.5	4.9	53.9	6.1	47.8	1.18
	8.5	4.2	54.3	5.0	49.3	1.19
	12.5	3.6	53.9	4.3	49.6	1.21
	16.5	2.8	53.9	3.2	50.7	1.20
	20.5	0.5	50.4	0.6	49.8	1.27
	24.5	0.1	56.2	0.1	55.1	1.14
3.9%	2.5	7.2	48.8	9.3	39.5	1.33
	6.5	3.2	49.6	4.2	45.4	1.31
	10.5	2.5	48.8	3.3	45.5	1.32
	14.5	2.3	47.7	1.7	46.0	1.36
	18.5	1.1	50.4	1.3	49.1	1.20
	22.5	0.02	49.2	0.00	49.2	1.32
5.6%	0.5	6.3	55.8	7.3	48.5	1.15
	4.5	6.2	51.6	7.7	43.9	1.26
	8.5	6.1	51.2	7.7	43.5	1.27
	12.5	6.0	51.2	7.6	43.6	1.27
	16.5	5.0	53.1	6.1	47.0	1.22
	20.5	3.6	51.2	4.6	46.6	1.27
	24.5	0.0	50.0	0.0	50.0	1.30
6.9%	0.5	7.6	53.9	9.2	44.7	1.20
	4.5	7.6	52.0	9.5	42.5	1.25
	8.5	7.3	49.6	9.5	40.1	1.31
	12.5	7.1	53.5	8.6	44.9	1.21
	16.5	7.1	53.5	8.6	44.9	1.21
	20.5	6.5	53.5	7.8	45.7	1.21
	24.5	5.9	50.4	7.6	42.8	1.29

movement differ, depending upon the amount of initial moisture. The maximum value is 3.6%; there is a decrease in the movement when the moisture is more or less than this. At large amounts of moisture of 7% or more, the movement speed is greatly reduced, and there is generally a small amount of moisture in motion. There is also a smaller amount in drying.

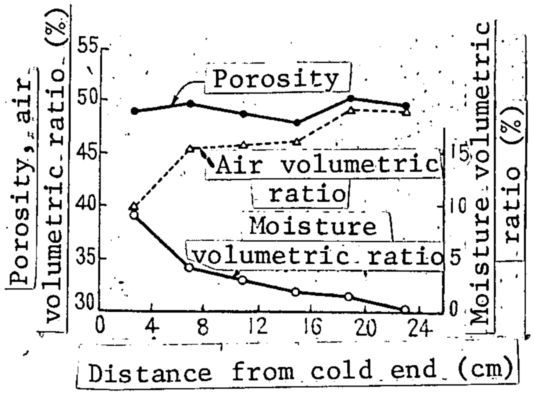

Figure 5. Examples of distribution of porosity, air volume, and moisture volume at final point (3.9%).

To give some examples, when there is an initial moisture of 3.6% and ∇T = 0.8° C/cm was administered for 72 hours, there is a pronounced reduction of the moisture on the warm side, where the moisture content is 0%. This indicates that all the moisture has moved. On the cold side, there is a pronounced increase, reaching about 200%. The sections where movement occurred going beyond the initial moisture extend up to the central part. This indicates that the temperature gradient led to a vapor pressure gradient, and that movement of moisture due to vapor diffusion occurred as a result. When we introduce the saturated vapor pressure with respect to the temperature, the vapor pressure is 100 mb on the warm side, and 35 mb on the cold side. The ratio is about 3, indicating that the pressure is about three times greater on the warm side, where the liquid water is evaporated and pushed out from the warm side towards the cold side as a vapor phase.

In order to make this easier to understand, let us rewrite Figure 3 (Figure 6). That is, the current amount is indicated as the remainder after the final moisture has been subtracted from the initial moisture content.

The position of the point of intersection with the abscissa — that is, the fact that the limit point surpassing the initial moisture moves closer towards the warm side as the amount of initial moisture increases — indicates that larger amounts of energy are needed to move a definite amount of moisture. In other words, this means that a large amount of energy is needed to evaporate liquid phase water and that the pores necessary to evaporate water inside the pores (porosity ratio minus moisture volumetric ratio) are small. Since they would all have identical curves if only an infinite time were given,

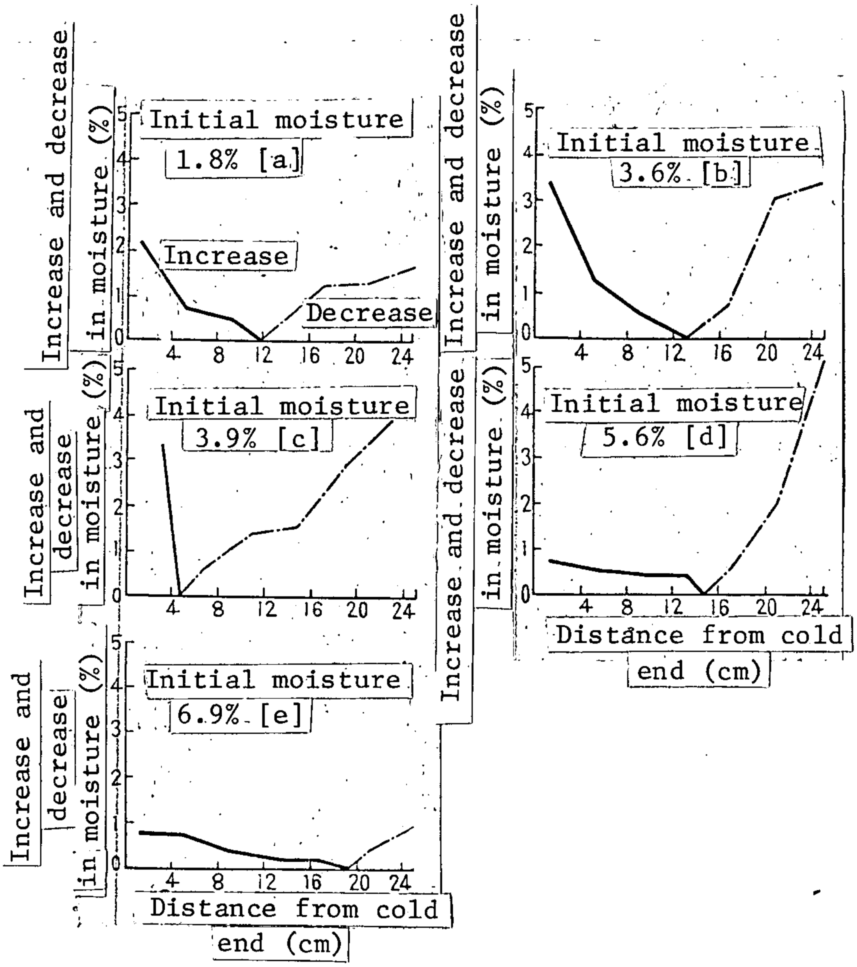

Figure 6. Increase and decrease in moisture in comparison with initial moisture. The data are the final moisture subtracted from the initial moisture. The solid lines indicate increases over the initial moisture; the broken lines indicate decreases under the initial moisture.

the fact that the intersection points tend to be located towards the warm side means that a corresponding duration of time is required. The second line in Table 3 gives the actual amount of movement (flow) per unit of area as sought from this figure.

(ii) <u>Amount of Movement Sought from the Theoretical Equation</u>

A comparison was made with the results of calculations by the theoretical equation, taking the test conditions into consideration. The ratio between these results and the actual amount of movement is shown in Table 3.

TABLE 3. COMPARISON BETWEEN ACTUAL AMOUNT OF MOVEMENT AND THEORETICAL VALUE.

Initial moisture	1.8%	3.6%	3.9%	5.6%	6.9%
Actual amount of movement	0.011	0.0181	0.023	0.015	0.0054
According to (∇T)	0.029	0.0177	0.021	0.027	0.0244
According to $(\nabla T)_a$	0.079	0.053	0.058	0.080	0.080
According to actual value/(∇T)	0.38	1.02	1.09	0.58	0.022
According to actual value/$(\nabla T)_a$	0.14	0.34	0.40	0.088	0.007

Note: "According to (∇T)" indicates the values found according to Penman's equation. "According to $(\nabla T)_a$" indicates the values found according to de Vries and Philip's equation.

When the amount of vapor diffusion obtained by Penman's equation is compared with the value actually obtained, there is very good correspondence near the point where the maximum transfer occurred. The ratio is 1.02 at 3.6%, and 1.09 at 3.9%. However, the results do not agree when there is more or less moisture than this.

When de Vries and Philip's method is used, there is a larger theoretical value, and the result is only 40% even at 3.9%, the point where there is maximum transfer.

These results differ greatly from the findings of other researchers in the past. Almost all of them found that the actual amount of movement was /103 several times to several dozen times greater. This is probably because of the manner of measuring the actual amounts, or because the testing time was short. Studies are currently being carried out on this point.

(iii) Maximum Transfer and Movement from the Viewpoint of Moisture Energy

In the sandy soil used in these experiments, with a grain composition of 0.175 - 0.50 mm, when there is a moisture ratio of 4% or less, the moisture assumes the pattern of hygroscopic moisture, most of which is in a state of non-liquid water. Consequently, since the capillary permeability in this case is 4%, at less than this movement it will occur only in the vapor phase. The maximum moisture transfer appears at an initial moisture of around 3.6%, because the capillary permeability is zero and counterflow caused by the moisture gradient does not occur around the beginning. When there is a moisture greater than this, the total amount of movement is less, but this is because there is a greater counterflow on account of the moisture gradient, which makes the amount of movement as a whole appear to be less. On the other hand, when the moisture is 3.6% or less, it may be assumed that the movement is less because the degree of moisture absorption by the hygroscopic moisture is greater, and also because there is a smaller absolute amount of moisture. The point where the maximum amount of transfer occurs corresponds to about one-third of the moisture equivalent.

As has been seen above in (i), (ii), and (iii), one may conclude that in soils with a low moisture content the movement of moisture is caused by vapor flow. When there is a temperature gradient, the vapor flow which occurs on account of the resulting vapor pressure moves away from the warm side towards the cold side. Because of the low temperature there, it is saturated and condensed. The reduction flow of the liquid phase occurs in the opposite direction, from the cold side to the warm side, on account of the moisture gradient occurring there as a result. The soil moisture distribution seen in Figure 3 expresses the results of the net movement of the moisture. That is, it must be attributed to the vapor flow moving from the warm side to the cold side; it is certain to have a magnitude greater than the liquid phase flow at the beginning. This is because the liquid phase flow will move to the extent allowed by the presence of the transmitting water film.

6. SUMMARY

Simple experiments were performed, using sandy soil, concerning the movement of soil moisture at a low moisture content, particularly when there is a temperature gradient. This report deals with the effects of the amounts of the initial moisture on the movement, when these amounts were varied in different ways. Studies were performed to establish whether the vapor diffusion equation applies or not.

The following findings were established as a result of the experiments:

(1) When there is a low moisture content, the soil moisture moves from the warm towards the cold, and its pattern is the vapor phase.

(2) The liquid phase water moves in the opposite direction on account of the moisture gradient after the passage of a suitable time. With respect to the total moisture transfer, it operates rather as a restricting element.

(3) The amount of movement differs depending upon the amount of initial moisture. In sandy soil (0.175 - 0.5 mm), the point of maximum transfer occurs within the range 3.6% - 4%. This corresponds to a point at about one-third of the moisture equivalent.

(4) The amount of movement is less than this when the initial moisture is more or less than this moisture. The amount decreases especially when the initial moisture surpasses 7%.

(5) The reason for (3) is because the capillary permeability is zero even at this point.

(6) The values sought by means of Penman's vapor diffusion theory coincide very well with the actual values near the maximum point, but they do not coincide elsewhere. It is thought that this is because the influence of the initial moisture is not taken into consideration.

7. CONCLUSION

In the foregoing, we have discussed the movement of soil moisture when there is a low moisture content from a very rudimental viewpoint, on the basis of simple experiments. At the present stage in this paper, we did not consider matters concerned with heat. However, it is obvious that this area is important in the final analysis. Further experiments will be made. In the second and following reports, we intend to make detailed analyses of movement based on the moisture gradient, movement based on the temperature gradient, and furthermore, the mechanism of movement, which was omitted in this first report.

In conclusion, we express our heartfelt gratitude to Professor Takeda Kyōichi of Kyushu University, Messrs. Sakaue Tsutomu and Matsuda Akimi, and the personnel of the Meteorological Department of Kyushu University, for the guidance they kindly provided in carrying out these experiments. Mr. Suzuki Yukio is also thanked for helping in the experiments.

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Translated for National Aeronautics and Space Administration under contract No. NASw 2035, by SCITRAN, P.O. Box 5456, Santa Barbara, California, 93108.